SF 298 MASTER COPY KEEP THIS COPY FOR REPRODUCTION PURPOSES

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
Final; 4/1/97 - 12/31/99

4. TITLE AND SUBTITLE
Ultrafast Electronic Processes in Semiconductor Nanostructures

5. FUNDING NUMBERS
DAAG55-97-1-0112

6. AUTHOR(S)
Sankar Das Sarma

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
Department of Physics
University of Maryland
College Park, MD 20742-4111

8. PERFORMING ORGANIZATION REPORT NUMBER
01-5-28477

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
ARO 35583.1-EL

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

We have completed the project finishing all the problems proposed in our original proposal. Our research advances the knowledge base in ultrafast electronic phenomena in semiconductor nanostructures. The project has led to more than 30 scholarly research articles and more than 20 invited talks in conferences.

14. SUBJECT TERMS

15. NUMBER IF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

TITLE
Ultrafast Electronic Processes in Semiconductor Nanostructures

TYPE OF REPORT
Final Progress

AUTHORS
Sankar Das Sarma, Distinguished University Professor, University of Maryland

DATE
February 2000

U.S. ARMY RESEARCH OFFICE

CONTRACT/GRANT NUMBER
DAAG 55 9710112

INSTITUTION
University of Maryland-College Park

Final Report on US-ARO
Grant DAAG559710112

A. Statement of the Problem Studied

Under this ARO grant support, we studied and completed all the theoretical and computational problems on ultrafast electronic processes in the semiconductor nanostructures, which we originally proposed in our grant proposal 35583-EL. The specific problems studied under this grant are band gap renormalization in semiconductor nanostructures particularly under high photo excitation conditions, collective mode mixing in quantum well structures, optical gain and lasing in semiconductor quantum wire nanostructures, slab and interface phonon induced thin film superconductivity, phonon induced spin relaxation, photon absorption and scattering in semiconductor nanostructures, and election scattering in artificial semiconductor nanostructures. As proposed in our original proposal, the completed projects under this ARO grant substantially advance our knowledge base in developing our understanding of ultrafast electronic processes in semiconductor nanostructures.

B. Summary of the Most Important Results

- *Band Gap Renormalization in Semiconductor Nanostructures.*
  We have calculated the many-body band gap renormalization in highly photo excited semiconductor quantum wire nanostructures by including electron-electron and electron-photon interactions as well as dynamical screening and self-energy corrections in our theory. Our numerical results, which are in excellent quantitative agreement with existing experimental results, give the shifts in the emission edge for proposed quantum wire lasers and nonlinear oscillators. We find that the calculated band gap renormalizations (BGR) follows an approximate universality, depending only on the dimensionless carrier density, for all the III-V semiconductor materials when the BGR is expressed in units of excitonic Ryolberg and the carrier density in the units of the effective Bohr radius.

- *Mode Mixing in Double Quantum Well Structures*
  We have carried out extensive quantum mean-field calculation to study intrasubband-intersubband mode mixing effects on many-body properties of semiconductor double quantum well structures. Our work shows that mode-mixing effects could be quantitatively important in a number of situations. We make several experimentally testable predictions.

- *Temperature Dependent Resistivity of Semiconductor Quantum Wires*
  We calculate the effects of dynamical screening and plasmon-phonon coupling on the electron-phonon scattering limited resistivity of semiconductor quantum wire nanostructures, finding that, in contrast to popular wisdom, many-body renormalization could significantly affect the low temperature acoustic phonon scattering limited quantum wire resistivity. In particular, we find, in agreement with several findings, that the "ordinary" Bloch-Gruneise temperature dependence

could be restored in one-dimensional quantum wires due to a subtle phonon renormalization effect.

- *Gain and Lasing in Semiconductor Nanostructures*
  We have developed a first principles many-body theory of optical absorption and emission in photo excited semiconductor quantum wires, demonstrating decisively the feasibility of using quantum wires as laser devices.

- *Thin Film Superconductivity*
  We have calculated the critical temperature for superconductivity in thin films by developing the Eliashberg theory including size-quantized slab and interface phonon modes. We find the distinct possibility of an enhanced superconducting transition temperature in thin films compared with bulk systems.

- *Phonon-Induced Spin Relaxation*
  Motivated by the possibility of spintronic devices (where spin plays the role of an active element) we have developed a theory for phonon-induced spin relaxation in electronic materials. Our initial calculations are in excellent quantitative agreement with the available experimental data in A1.

- *Inelastic Light Scattering in Semiconductor Nanostructures*
  We have developed a many-body theory (which takes into account detailed band structure effects) for inelastic light scattering by free carriers in semiconductor nanostructures. Our theory explains a 25-year-old experimental puzzle in the literature about the occurrence of a single particle excitation peak in the light scattering spectra.

- *2D Metal-Insulator Transition*
  We have developed a quantitative theory for the 2D metal-insulator transition including effects of screening and degeneracy in the presence of electron-impurity and electron-phonon interaction. Our work explains a large number of recent puzzling experimental observations.

C. List of Publications

1. Exchange Instabilities in Semiconductor Double-Quantum-Well Systems (L. Zheng, M.W. Ortalano, and S. Das Sarma) Phys. Rev. B. 55, 4506 (1997).

2. Realistic Calculations of Correlated Incompressible Electronic States in GaAs-$Al_xGa_{1-x}As$ Heterostructures and Quantum Wells (M.W. Ortalano, Song He, and S. Das Sarma) Phys. Rev. B. 55, 7702 (1997).

3. Spin-Excitation-Instability-Induced Quantum Phase Transitions in Double-Layer Quantum Hall Systems (L. Zheng, R.J. Radtke, and S. Das Sarma) Phys. Rev. Lett. 78, 2453 (1997).

4. Persistent Current in an Artificial Quantum Dot Molecule (R.Kotlyar and S. Das Sarma) Phys. Rev. B (Rapid Communications) 55, R10 205 (1997).

5. Dynamic Scaling in a 2+1 Dimensional Limited Mobility Model of Epitaxial Growth (S. Das Sarma and P. Punyindu) Phys. Rev. E 55, 5361 (1997).

6. Coherent Magnetotransport Through an Artificial Molecule (C.A. Stafford and S. Das Sarma) Phys. Lett. A 230, 73 (1997).

7. Unusual Temperature Dependent Resistivity of a Semiconductor Quantum Wire (Lian Zheng and S. Das Sarma) Solid State Commun. 104, 629 (1997).

8. Nonlinear Transport through Coupled Double Quantum Dot Systems (R. Kotlyar and S. Das Sarma) Phys. Rev. B 56, 13235 (1997).

9. Harmonic Solid Theory of Photoluminescence in the High Field Two-Dimensional Wigner Crystal (S. Kodiyalam, H.A. Fertig, and S. Das Sarma) Phys. Rev. B 56, 12344 (1997).

10. Double-Layer Quantum Hall Antiferromagnetism at Filling Fraction $\nu = 2/m$ where m is an Odd Integer (S. Das Sarma, Subir Sachdev, and Lian Zheng) Phys. Rev. Lett. 79, 917 (1997).

11. Growth of Si on the Si(111) Surface (C.J. Lanczycki, R. Kotlyar, E. Fu, Y.-N. Yang, E.D. Williams, and S. Das Sarma) Phys. Rev. B 57, 13132 (1998).

12. Mode Mixing in Antiferromagnetically Correlated Double Quantum Wells (R. J. Radtke, S. Das Sarma, and A. H. MacDonald) Phys. Rev. B 57, 2342 (1998).

13. Extended Self-similarity in Kinetic Surface Roughening (A. Kundagrami, C. Dasgupta, P. Punyindu, and S. Das Sarma) Phys. Rev. E (Rapid Communications) 57, R3703 (1998)

14. Noise Reduction and Universality in Limited Mobility Models of Nonequilibrium Growth (P. Punyindu and S. Das Sarma) Phys. Rev. E (Rapid Communications) 57, R4863 (1998).

15. c-axis Optical Reflectivity of Layered Cuprate Superconductors (S. Das Sarma and E. H. Hwang) Phys. Rev. Lett. 80, 4753 (1998).

16. Addition Spectrum, Persistent Current, and Spin Polarization in Coupled Quantum Dot Arrays: Coherence, Correlation, and Disorder (R. Kotlyar, C. A. Stafford, and S. Das Sarma) Phys. Rev. B 58, 3989 (1998).

17. Band Gap Renormalization in Photoexcited Semiconductor Quantum Wire Structures in the *GW* Approximation (E.H. Hwang and S. Das Sarma) Phys. Rev. B (Rapid Communications) 58, R1738 (1998).

18. Canted Antiferromagnetic and Spin Singlet Quantum Hall States in Double-Layer Systems (S. Das Sarma, S. Sachdev, and L. Zheng) Phys. Rev. B 58, 4672 (1998).

19. Coherent Resonant Tunneling Through an Artificial Molecule (C.A. Stafford, R. Kotlyar, and S. Das Sarma) Phys. Rev. B 58, 7091 (1998).

20. Correlated Charge Polarization in a Chain of Coupled Quantum Dots (R. Kotlyar, C.A. Stafford, and S. Das Sarma) Phys. Rev. B (Rapid Communications) 58, R1746 (1998).

21. Bilayer to Monolayer Charge-Transfer Instability in Semiconductor Double-Quantum Well Structures (S. Das Sarma, M. Ortalano, and L. Zheng) Phys. Rev. B 58, 7453 (1998).

22. Plasmons in Coupled Bilayer Structures (S. Das Sarma and E.H. Hwang), Phys. Rev. Lett. 81, 4216 (1998).

23. Spin Relaxation of Conduction Electrons in Polyvalent Metals: Theory and a Realistic Calculation (J. Fabian and S. Das Sarma), Phys. Rev. Lett. 81, 5624 (1998).

24. Resistivity Saturation Revisited: Results from a Dynamical Mean Field Theory (A.J. Millis, J. Hu, and S. Das Sarma), Phys. Rev. Lett. 82, 2354 (1999).

25. Spin Bose Glass Phase in Bilayer Quantum Hall Systems at *nu* = 2 (E. Demler and S. Das Sarma), Phys. Rev. Lett. 82, 3895 (1999).

26. A Few Electrons per Ion Scenario for the B=0 Metal-Insulator Transition in Two Dimensions (T.M. Klapwijk and S. Das Sarma), Solid State Commun. 110, 581 (1999).

27. Collective Charge Density Excitations in Two-Component One-Dimensional Quantum Plasmas: Phase Fluctuation Mode Dispersion and Spectral Weight in Semiconductor Quantum Wire Nanostructures (S. Das Sarma and E.H. Hwang), Phys. Rev. B 59, 10730 (1999).

28. A Discrete Model for Nonequilibrium Growth under Surface Diffusion Bias (S. Das Sarma and P. Punyindu), Surf. Sci. Lett. 424, L339 (1999).

29. Charged Impurity Scattering Limited Low Temperature Resistivity of Low Density Silicon Inversion Layers (S. Das Sarma and E.H. Hwang) Phys. Rev. Lett. 83, 164 (1999).

30. Electromodulation of the Bilayer nu=2 Quantum Hall Phase Diagram (L. Brey, E. Demler, and S. Das Sarma) Phys. Rev. Lett. 83, 168 (1999).

31. Sign-Time Distributions for Interface Growth (Z. Toroczkai, T.J. Newman, and S. Das Sarma), Phys. Rev. E (Rapid Commun.) 60, R1115 (1999).

32. Resonant Raman Scattering by Elementary Electronic Excitations in Semiconductor Structures (S. Das Sarma and D.W. Wang), Phys. Rev. Lett. 83, 816 (1999).

33. Phonon-Induced Spin Relaxation of Conduction Electrons in Aluminum (J. Fabian and S. Das Sarma), Phys. Rev. Lett. 83, 1211 (1999).

D. List of Participating Personnel

1. Sankar Das Sarma, Distinguished University Professor, University of Maryland, PI

2. Euyheon Hwang, Research Associate (Ph.D. received in 1996-97 under ARO support)

3. Daw-Wei Wang, Research Assistant (Ph.D. received in summer 2000 under ARO support)